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Evaluating Hydrogel Application on Soil Water Availability and Crop Productivity in Semiarid Tropical Red Soil

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ABSTRACT: The insufficient root zone soil moisture is the most important limitation for crop productivity on light texture soils of semiarid and arid regions. Application of super absorbent polymers in to the soil could be one of effective means to increase water use efficiency in crops. Laboratory and field investigations were carried out to evaluate the water retention and release characteristics of hydrogels and to evaluate its effect on crop productivity during *kharif* and *rabi* seasons in semiarid red soils. Overall, the amount of water absorbed by one gram of polymer ranged between 332 and 465 g (in distilled water) and about 91-96% of absorbed water was released within 15 bar tension i.e., permanent wilting point. Hydrogel was not found effective for groundnut and pigeonpea crop during *kharif* season but showed positive effect on tomato when it was tested @ 25-100 kg/ha. The agronomic efficiency of polymers application for tomato was highest when polymers were applied @ 50 kg/ha and it was 58 kg tomato fruit per kg of polymer application. In case of tomato grown during *rabi* season, it was observed that at least one irrigation in every three weeks can be postponed by applying polymers. This helped in recording the water productivity to the extent of 279 kg/ha mm and saved 210 ha mm irrigation water in entire crop growth period.

Key words: Polymers, sandy soils, available water capacity, tomato, redgram, groundnut, water productivity

The major thrust of dryland crop production system in arid and semiarid region is increasing efficiency of water use. Climate of these regions is characterized by seasonal rainfall, intermittent dry spells, recurrent drought years and high evaporative demand. Soils in arid and semiarid regions are often characterized by low clay and organic matter contents which result in low water holding capacity (Abdelfattah, 2013; Mandal *et al.,* 2011), and soils often have inherently low-fertility and are vulnerable to erosion (Falkenmark and Rockström, 2004).

One of the means to increase the water content in this soil is the use of super absorbent synthetic polymers as soil conditioners, which increase water retention in root zones region of the soil. These super absorbent polymers or hydrogels are compound that absorb water and swell into many times of their original size and weight and are used in soil to create a water reserve near the rhizosphere zone (roots) and benefit agriculture (Zohuriaan-Mehr and Kabiri, 2008; Han *et al.*, 2010). The hydrogel polymers lead to increased water use efficiency since water that would have otherwise leached beyond the root zone is captured. When these polymers are incorporated into the soil, it is presumed that they retain large quantities of water and nutrients, which are released as required by the plant (Bhardwaj *et al.*, 2007). Indeed, polymers which have been used for this purpose are safe and non-toxic and will eventually decompose to carbon dioxide, water and ammonia and potassium ions, without any residue (Mikkelsen, 1994; Trenkel, 1997).

Sojka *et al.* (2007) critically reviewed the use of polymers in agriculture and environment land management. Water soluble polymers were first used during World War II to stabilize soils for road and runway construction. Since 1950s, soil scientists have explored using synthetic polymeric conditioners to alter physical and, in some cases, chemical and biological soil properties for improved agricultural performance. Water-soluble polymeric conditioners improved soil physical properties, thereby improving root penetration, infiltration, aeration, erosion resistance, and drainage. Polymers achieve these results when applied to soil via the irrigation water or by spraying on to the soil surface, by stabilizing soil structure, reducing the tendency of soils to form seals, thereby preventing decline in infiltration rates, reducing runoff and soil losses (Levy *et al.,* 1995; Ben-Hur, 2006). The most commonly used water-soluble synthetic soil-conditioning polymers since 1950s included hydrolyzed polyacrylonitrile (HPAN), isobutylene maleic acid (IBM), polyacrylamide (PAM), polyvinyl alcohol (PVA), sodium polyacrylate (SPA), and vinylacetate maleic acid (VAMA).

The most commercially successful water-soluble soil–conditioning polymer marketed before the 1990s was Monsanto product 'Krilium'. The cost of material and application limited its use mainly to high-value crops and specialized uses. Hydrogels are not water-soluble, but rather strongly hydrophilic gels forming cross-linked PAM polymers made up of water-insoluble acrylamide and potassium acrylate and have long parallel chains of molecules and when cross-linked they create a network of polymeric chains. Water is brought into the network through the process of osmosis and quickly moves into the central part of the polymer network, where it is reserved. When the hydrogels act as absorbing agents and take on the outward appearance of a gel and can absorb up to 500 times their weight in water, and when their surroundings begin to dry out, the cross-linked PAM gradually dispense up to 95% of their stored water. These properties are what make hydrogels attractive to the agricultural world.

As soil conditioners, they improve the water retention in sandy soil or around seeds, or roots of transplants or seedlings in situations where prolonged or untimely drought can occur, especially at planting. Spot placement of gel polymers can enhance emergence and seedling establishment without irrigating the entire soil profile. These gel polymers conserve water by enhancing water storage.

The polymers do not reduce the water demand or use, but can buffer the root zone against water loss in soils with low water retention properties. Despite the potential benefits, costs were usually too high to modify an entire field's soil profile or its tillage zone or rooting depth using these polymers. Thus, their use is typically restricted to high-value nursery or horticultural plants to reduce irrigation frequency, or to lessen the stress between irrigations, particularly where plant or crop quality and value are impaired by stress.

Since sixties and early nineties, polymer purity and molecular size had increased, which greatly improved its efficacy, safety and affordability. These changes, coupled with new application strategies that only target critical portions of the soil for treatment, and that do not require expensive application protocols, have renewed interest in polymers for a growing number of agricultural and environmental uses. In India, very little research work has been done on polymers application in agriculture. Systematic field studies under arid and semi-arid conditions of India are needed to develop appropriate rate, frequency and method of application of different polymers to various crops and to assess economics of use of different polymers (Sammi Reddy *et al.*, 2013). Most synthetic polymers achieve their desired effects at application of 100 kg/ha or less compared to tonnes per hectare, as in is the case of most organic or mineral conditioners (Sojka *et al.*, 2007). Sammi Reddy *et al.* (2013) reported that the rate of application of polymers recommended by different polymer suppliers varied from 2.5 kg/ha to 60 kg/ha depending upon type of polymer, method of application, crop, etc. The longevity of polymers in soils is another issue to know its residual effect.

The present investigations aimed at studying water retention and release characteristics of hydrogels and assessing its efficacy on productivity of groundnut, pigeonpea and tomato in semiarid tropical red soil.

Materials and Methods

Laboratory investigations

To determine the rate of absorption of water by the polymer, 1 g polymer was placed in a beaker and the beaker was filled with 1 litre of distilled water (Electrical Conductivity 0.01 dS/m). Polymers were allowed to remain in water for 2 hours. The excess water was drained through a 106 µm sieve for five minutes and the weight of hydrated material was recorded. The water retained by polymer was expressed as g water absorbed per 1 g polymer. The hydrated polymer samples were used for determining the amount of water released from polymers and water retained in the polymers after subjecting to the 0.33 bar (field capacity, FC) and 15 bar (permanent wilting point, PWP) tension using pressure plate apparatus. After removing the polymer samples from the pressure plate apparatus, wet weights were recorded and were dried in oven at 105°C for 24 hours. Available water was determined by subtracting moisture content at the FC (0.33 bar pressure) from the PWP (15 bar pressure) value.

Sequoia Biosolutions Pvt. Ltd., Pune developed a long chain crossed linked acrylic based polymers with a trade name 'Bhagiratha'. The hydrogel polymer Bhagiratha along with commercially available four hydrogel polymers in Israel denoted as SB1, SB2, SB3 and SB4 were tested in the laboratory.

The hydration of polymers was also studied in each cycle of wetting and drying. The polymers were saturated and their weights were noted and dried at 60°C. Again, it was saturated and dried for eight cycles.

The effect of polymers on soil moisture retention was studied for 24 days in the laboratory in plastic container. A sandy clay loam soil (sand 63%, silt 5.6% and clay 31.4%) was sieved through 2 mm sieve and 0.5% (4 g) and 0.25% (2 g) of each polymer was mixed thoroughly with 800 g air dried soils and saturated it with distilled water. The moisture depletion was recorded every day.

Field experiment sites

The experiments were conducted at Hayatnagar (HRF) (around 14 km from Hyderabad) (17°20'N latitude, 78°35'E longitude, and an elevation of 515 m above mean sea level) and Gunegal (around 43 km from Hyderabad) Research Farm (GRF) (Latitude 17°6'N, Longitude 78°40'E and 542 m above msl) of ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, India, during 2010-2011. The climate of the region is semi-arid with hot summers and mild winters. The mean annual rainfall received at Hayathnagar is 750 mm and that at Gunegal is 690 mm and it accounts for approximately 40% of the annual potential evapotranspiration for both the farms. Nearly, 70% of the total precipitation is received during the southwest monsoon season (June to September) and the remaining period of the year is generally dry. During the summer months (April, May and June), temperatures rise to 45°C. The soil is a medium-textured sandy clay loam type, red soil (*Typic Haplustalf*) as per USDA soil classification for HRF and *Typic Rhodustalfs* for GRF (Table 1). The landscape is characterized by mild slopes (<1%).The surface soil has a low water holding capacity; it is highly permeable and readily drains. The soil pH is neutral to slightly acidic. Total annual rainfall received during 2010 was 1103 mm and 780.8 mm in Hayatnagar and Gunegal research farm, respectively.

Table 1 : Soil properties of experimental sites at Hayatnagar and Genegal Research Farm of ICAR-CRIDA

Parameter	Hayatnagar	Gunegal
Soil texture	Sandy clay loam	Sandy clay loam
Soil Taxonomy	Typic Haplustalf	Typic Rhodu-stalf
pH	6.3	6.8
EC (dS/m)	0.21	0.56
Available N (kg/ha)	113	138
Available P (kg/ha)	26	34
Available K (kg/ha)	197	301
Exchangeable Ca (cmol/kg)	2.1	4.3
Exchangeable Mg(cmol/kg)	0.53	0.91
Cation Exchange capacity(cmol/kg soil)	14.5	16.2
Exchangeable sodium percentage (%)	2.6	4.1
Soil water retention at 0.33 bar % (w/w)	10.1	12.2
Soil water retention at 15.0 bar % (w/w)	4.7	5.5
Available water capacity % (w/w)	5.4	6.7

Experiment details

Three crops i.e., groundnut (*Arachis hypogaea*) and pigeonpea (*Cajanus cajan*) at Hayatnagar Research Farm and tomato (*Lycopersicon esculentum*) at Gunegal research farm were grown during *kharif* season of 2010 for knowing the efficacy of hydrogel on crop productivity. Groundnut (variety: Narayani) and pigeonpea (variety: PRG 158) were sown during 1st week of July in HRF. Tomato seedlings (variety: Samrat-18) was transplanted during the last week of July in GRF. Both the experimental sites have sandy clay loam red soil.

The experiment was laid as a randomized block design (RBD) with three replications and four treatments (T1: 25 kg plolymer/ha, T2: 50 kg polymer/ha, T3: 100 kg polymer/ha and T4: control or without polymer for groundnut and tomato; and for pigeonpea T1: 28 kg plolymer/ha or 2.5 g/m, T2: 56 kg polymer/ha or 5 g/m, T3: 84 kg polymer/ha or 7.5 g/m and T4: control or without polymer). For groundnut crop, a fertilizer dose of 20 kg N and 50 kg P as diammonium phosphate along with 1t gypsum per ha were applied at the time of sowing in all the plots uniformly, whereas, for redgram, a dose of 22 kg N and 25 kg P as diamonium phosphate was applied uniformly in all the plots just after crop establishment. The groundnut and pigeonpea were harvested on 18th October 2010 and 4th January 2011, respectively.

In case of tomato, all plots received uniform dose of N, P, and K at 80, 50, 25 kg/ha, respectively. Half of the N and entire dose of P and K were applied at the time of transplanting as basal dose, remaining half N applied in two equal splits at 20 and 40 days after transplanting. Tomato was transplanted on 27th July 2010 and harvesting of fruits was carried out through four pickings during October, 2010.

Groundnut and tomato were grown as test crops for *rabi* season at HRF. *Rabi* field experiment was laid in RBD with three replications and 5 treatments viz. T1: Irrigation every week + polymer @ 100 kg/ha, T2: Irrigation alternate week + polymer @ 100 kg/ha, T3: Irrigation every 3rd week + polymer @ 100 kg/ha, T4: No irrigation + polymer @ 100 kg/ha, T5: Irrigation alternate week + No polymer for both groundnut and tomato crop. The amount of water applied was 20 mm for each irrigation with non-saline water (EC: 1.08 dS/m; pH: 7.58; Na: 3.31 mg/l; Ca: 2.4 mg/l). Similar nutrient management practices were followed for *rabi* groundnut and tomato crops as were followed in *kharif* season. Recommended package of practices were followed for weed, pest and disease control for both *kharif* and *rabi* crops. In no irrigation treatment, light water was applied for crop establishment up to 3 weeks and at the time of fertilizer application. Groundnut was harvested on March 16, 2011, whereas tomato fruit was harvested during February-March, 2011 through 9 pickings. The polymer Bhagiratha was used for field testing. Polymers were applied with fertilizer just below the seed in seeding rows at 5-10 cm depth at the time of seeding in groundnut and pigeonpea crops, whereas in tomato, polymer was applied to each tomato plant at the time of transplanting as band placement by making hole with a stick at root depth.

Soil and plant analysis

Soil samples were collected from the experiment sites from 0-15 cm depth, air dried and passed through 2 mm sieve for analyzing a number of physical and chemical properties of soil. Soil water retention at both field capacity and the permanent wilting point was measured using pressure plate apparatus at 0.33 bar and 15 bar, respectively. Available water was determined by subtracting the field capacity value from the permanent wilting point value. A part of the soil samples was air dried, crushed and passed through a 0.2-mm sieve for organic carbon determination by the Walkley-Black method. Available soil nitrogen was determined by alkaline-$KMnO_4$ method, which addresses easily oxidizable N. Available P (Olsen P) was determined by sodium bicarbonate ($NaHCO_3$) extraction and subsequent colorimetric analysis. Exchangeable K was determined by emission spectrometry of 1N ammonium acetate extracts. The leaf area index (LAI) was monitored using Sun Scan canopy analysis system (Delta-T Devices, Ltd. UK).

Representative plant samples were collected from each plot and analyzed for N, P and K. Total N was determined by digesting plant samples using the semi-kjeldahl method of Bremner and Mulvaney (Bremner and Mulvaney, 1982). For determination of total P and K, plant samples were digested in a tri-acid mixture (HNO_3: $HClO_4$: H_2SO_4 at 3:1:1 ratio). Total P and K were determined in the digests using the Vanadomolybdate yellow colour method in spectrophotometer and by flame photometer, respectively (Jackson, 1973). Total N, P, and K were computed from the dry matter yield and nutrient concentration.

The data from field experiment on yield, dry matter yield, nutrient uptake etc. were subjected to standard analysis of variance. The significance of the treatment effect was determined using the F-test, and to determine the significance of the difference between the means of the two treatments, least significant differences (LSD) were estimated at the 5% probability level (Gomez and Gomez, 1984).

Results and Discussion

Laboratory investigations

Bhagiratha along with other four groups of hydrogels were studied in the laboratory for its efficacy. On an average, polymers hold 332-465 times water of its weight (Table 2). Around 72-82% of absorbed water was released within zero to 0.33 bar soil moisture tension. When subjected to 15 bar tension, about 91-96% of absorbed water was released. These results clearly show that the water held in polymer can easily be available to plants. Joao *et al.* (2007) reported that more than 90% of water absorbed by polymer was available to plant roots. On an average, at 15 bar tension, polymers hold water only 23 times of its weight. The available water to plant in polymers varied between 313-427 times of its weight.

The wetting and drying cycles were studied for eight cycles to know if the polymers were equally effective in hydration in each wetting and drying cycle and after eight cycles of wetting and drying, it was noted that around 46-64% of its water absorbing capacity was reduced (Table 3). Generally, in each crop growth period, there was at least 8-10 cycles of wetting and drying through intermittent rain or irrigation and drought. After 8 cycles of wetting and drying, the residual effect of polymer was around 50% in terms of water absorbing capacity.

The data on soil moisture content recorded after applying water to saturation in different polymer treatments showed that moisture content was influenced by time and amount of polymers added in soils. During all the 24 days of study, soils treated with polymers showed higher moisture content than those without polymers (Figure 1). When normal soils reached permanent wilting point (w/w % soil moisture content around 5%) in ten days, it took around 16 days for 0.25% treated polymers soils and 20 days for 0.5% polymers treated soil to attain PWP. After 13 days of drying, when soils without polymer held just 1.9% moisture, the soils amended with 0.5% polymers treatment recoded 14% moisture and 0.25% polymers mixed soil recorded 9% moisture. Even after 24 days, soils with polymers SB3 and SB4 held around 6% moisture, which was more than PWP of the untreated soils studied.

Table 2 : Amount of water held at saturation, at 1/3 bar and 15 bar tension by different polymers

Type of polymers	Amount of water (g) held at saturation by one g polymer	Amount of water (g) held at 0.33 bar tension by one g polymer	Amount of water (g) hold at 15 bar tension by one g polymer	Available water to plant
SB1	436.6 ± 12.1*	98.4 ± 5.6	24.8 ± 3.1	411.8
SB2	332.4 ± 10.1	58.6 ± 2.3	19.3 ± 2.3	313.1
SB3	465.5 ± 7.8	87.1 ± 4.1	38.3 ± 4.1	427.2
SB4	355.7 ± 8.9	72.5 ± 1.8	21.2 ± 1.8	334.5
Bhagiratha	382.1 ± 9.1	105.6 ± 4.3	12.8 ± 4.3	369.3
Average	394.5	84.4	23.3	371.2

*Standard deviation

Table 3 : Percent depletion of water holding capacity of different polymers at saturation after each cycle of wetting and drying

Polymers	1st cycle	2nd cycle	3rd cycle	4th cycle	5th Cycle	6th cycle	7th cycle	8th cycle
SB1	100	15.5	19.5	36.9	45.3	48	51	58
SB2	100	12.2	36.3	37.9	41.9	42.8	43	46
SB3	100	48.9	50.1	51.9	55.3	56	57	59
SB4	100	33.5	35.9	40.7	43.1	51	52.8	57
Bhagiratha	100	34.7	36.9	58.4	61.4	62	63.6	64

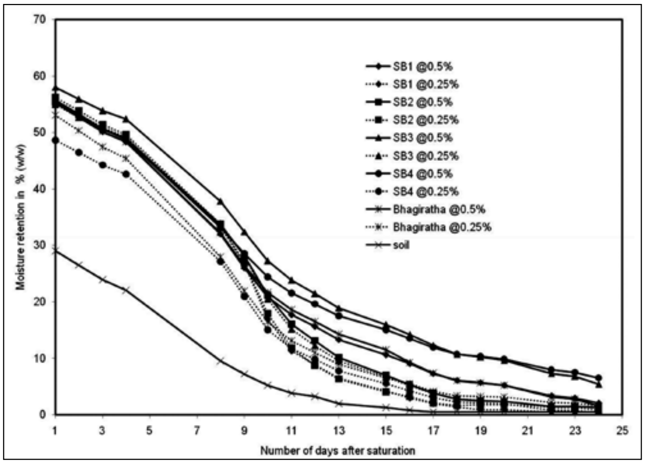

Fig. 1 : Effect of polymers applied (@ 0.5% and 0.25% (w/w) with sandy clay loam soils on moisture retention (%) (w/w) as a function of time after saturation with distilled water

Hydrogel application for *kharif* crop

In case of groundnut crop, there was no significant difference in groundnut pod yield as well as dry biomass yield, nutrient uptake and soil properties under different levels of polymer treatments (Tables 4 & 5). During the year 2010, total 691.8 mm rainfall was received in 40 rainy days at HRF during the entire crop growth period (July-October), which met the entire crop water requirement of groundnut crop (50-70 cm). There was not a single dry spell week except one week before harvesting during the crop growth period. In case of treatment T3 where polymer was applied @ 100 kg/ha there was slight increase in soil moisture status particularly in surface layer compared to other treatments towards the harvesting stage of groundnut. Considerable earthworm castings were noted in all polymer treated plots, indicating that polymers did not reflect any antagonistic effect to soil biological activity.

Similar to groundnut, in case of pigeonpea, there was no significant difference in grain and dry biomass yield, and nutrient uptake as well as soil properties under different levels of polymer treatments (Tables 6 & 7). This might be because distribution of rainfall was quite good during the growing season. A total amount of 845.9 mm rainfall was received in 49 rainy days at HRF during the entire pigeonpea crop growth (July-December). Only few dry spells were recorded during the maturity stage of the crop (end of November and December). Though in treatment T3, where polymer was applied @ 84 kg/ha, there was increase in soil moisture status at different depths than other treatments, but it was not reflected in crop yield.

In tomato crop, the highest fruit yield was recorded in T3 treatment followed by T2, T1 and lowest in control T4 treatment (Tables 8 & 9). There was no significant effect on tomato fruit yield obtained with polymers applied @50 kg/ha (T2) and 100 kg/ha (T3). The overall agronomic efficiency of polymers application was 58 kg and 35 kg tomato per kg of polymer application when polymers were applied @50 kg/ha and 100 kg/ha, respectively. There was also significant difference in case of dry biomass yield as well as nutrient uptake, and trend was similar as observed in tomato fruit yield. But there was no significant difference among the treatments in terms of soil properties studied after the harvest of tomato crop. In total, 211 mm rainfall was received in 24 rainy days at GRF during the entire tomato crop growth period, which was 50% less than the rainfall received at HRF during same period. There was dry spell during the maturity stage of the crop (end of November and December). Tomato is an indeterminate type of crop, where flowering is in flushes. Entire crop was harvested through four pickings. When polymer was not effective in case of groundnut and pigeonpea in HRF with good rainfall distribution in 2010, there was yield increase with polymer application in GRF in case of tomato where harvesting was done through number of pickings.

Hydrogel for *rabi* crop

Groundnut and tomato were sown during *rabi* season in sandy clay loam soils of HRF. The treatment T1 which received irrigation in every week as well as polymer @ 100 kg/ha at the time of sowing recorded the highest dry biomass and pod yield for groundnut (Table 10). Very low yield in T4 treatment indicated that it was not feasible to grow groundnut without irrigation in *rabi* season even with polymer. In case of T1 treatment, total 260 mm (14 numbers of irrigation) in T2 and T5, total 130 mm each (7 numbers of irrigation) and in T3, total 90 mm (5 numbers of irrigation) water was applied as irrigation. The treatment T4 didn't receive any irrigation except light watering for first three weeks and at the time of fertilizer and gypsum application. Along with

Table 4 : Yield, LAI (leaf area index at 68 Days after sowing) and nutrient uptake for groundnut crop under different rates of polymer (Bhagiratha) applications during *kharif* season in HRF

Treatments	LAI	Dry biomass yield	Pod yield	Total N uptake	Total P uptake	Total K uptake
		(kg/ha)				
T1,(@ 25 kg polymer/ha	4.5	5405	1137	55.9	28.6	77.4
T2,(@ 50 kg polymer/ha	4.1	6050	1330	63.5	32.6	87.8
T3, (@ 100 kg polymer/ha	4.3	6167	1213	62.3	31.8	86.6
T4, control @ 0 polymer/ha	4.4	5418	1271	58.2	30.0	80.3
LSD (5% level)	NS	NS	NS	NS	NS	NS

NS; not significant

Table 5 : Soil properties after harvesting of groundnut crop under different rates of polymer (Bhagiratha) application during *kharif* season in HRF

Soil parameters	Soil after harvesting of crop				LSD (5% level)
	T1	T2	T3	T4	
Organic carbon (%)	0.630	0.603	0.601	0.613	NS
Available N (kg/ha)	180.2	155.5	167.7	154.7	NS
Available P (kg/ha)	24.7	26.9	26.2	24.5	NS
Exchangeable K (kg/ha)	191.7	181.2	216.8	164.7	NS
Soil water retention at 0.3 bar (%) (w/w)	10.07	9.81	9.77	10.44	NS
Soil water retention at 15bar (%) (w/w)	4.54	4.39	4.44	4.52	NS
Available water capacity % (w/w)	5.53	5.42	5.33	5.92	NS

Table 6 : Yield, LAI (leaf area index at 68 Days after sowing) and nutrient uptake for pigeonpea crop under different rates of polymer (Bhagiratha) applications during *kharif* season in HRF

Treatments	LAI	Dry biomass yield	Grain yield	Total N uptake	Total P uptake	Total K uptake
		Kg/ha				
T1, @ 28 kg polymer/ha	2.1	6928	1550	89.2	54.3	120.0
T2, @ 56 kg polymer/ha	2.7	6658	1403	85.0	50.4	114.5
T3, @ 84 kg polymer/ha	2.6	6669	1447	86.0	51.1	116.0
T4, control @ 0 polymer/ha	2.7	6414	1381	82.5	49.0	111.2
LSD (5% level)	NS	NS	NS	NS	NS	NS

Table 7 : Soil properties after harvesting of pigeonpea crop under different polymer rates of polymer (Bhagiratha) application during kharif season in HRF

Soil parameters	Soil properties after harvesting of crop				LSD (5% level)
	T1	T2	T3	T4	
Organic carbon (%)	0.471	0.417	0.417	0.497	NS
Available N (kg/ha)	101.3	99.4	112.3	96.8	NS
Available P (kg/ha)	22.94	22.0	23.1	24.7	NS
Exchangeable K (kg/ha)	191.2	172.8	196.3	173.2	NS
Soil water retention at 0.33 bar (%) (w/w)	11.46	11.42	11.29	11.12	NS
Soil water retention at 15 bar (%) (w/w)	4.36	4.76	5.19	4.90	NS
Available water capacity % (w/w)	7.10	6.66	6.10	6.22	NS

Table 8 : Yield, LAI (Leaf area Index at 45 Days after transplanting) and nutrient uptake for tomato under different rates of polymer (Bhagiratha) applications during *kharif* season in GRF

Treatment	Leaf area Index	Fruit yield	Dry biomass yield	Total N Uptake	Total P Uptake	Total K Uptake	Agronomic efficiency
				Kg/ha			kg fruit yield/kg polymer
T1, @ 25 kg polymer/ha	2.5	16500	2387	29.4	21.2	31.0	12.08
T2, (@ 50 kg polymer/ha	2.7	19104	2937	35.2	25.2	37.3	58.12
T3, @ 100 kg polymer/ha	2.6	19750	3073	36.6	26.2	38.9	35.52
T4, control @ 0 polymer/ha	2.2	16198	2323	28.7	20.8	30.2	
LSD (5% level)	NS	1292	510	7.1	4.4	8.4	

Table 9 : Soil properties after harvesting of tomato under different rates of polymer (Bhagiratha) application during *kharif* season in GRF

Soil parameters	Soil after harvesting of crop				LSD (5% level)
	T1	T2	T3	T4	
Organic carbon (%)	0.663	0.717	0.680	0.697	NS
Available N (kg/ha)	112.16	119.52	118.75	120.42	NS
Available P (kg/ha)	32.06	37.88	36.80	36.51	NS
Exchangeable K (kg/ha)	298.85	294.89	248.75	315.09	NS
Soil water retention at 0.3bar (%) (w/w)	13.66	12.15	13.63	13.58	NS
Soil water retention at 15 bar (%) (w/w)	5.20	4.92	5.44	6.06	NS
Available water capacity % (w/w)	8.46	7.23	8.19	7.52	NS

Table 10 : Yield, LAI (Leaf area Index at 77 Days after transplanting), water productivity and nutrient uptake for groundnut under polymer (Bhagiratha) and irrigation treatments during *rabi* season in HRF

Treatment	LAI	Dry biomass yield	Pod Yield	Total N Uptake	Total P Uptake	Total K Uptake	Water productivity
		Kg/ha					Kg pod ha/mm
T1, Irrigation every week+polymer @ 100 kg/ha	3.1	6750	704	56	28	80	2.71
T2, Irrigation alternate week + polymer @ 100 kg/ha	2.4	5303	622	49	26	72	4.78
T3, Irrigation every 3rd week + polymer @ 100 kg/ha	2.3	3441	153	28	14	41	1.7
T4, No irrigation + polymer @ 100 kg/ha	1.6	3055	65	22	10	32	
T5 Irrigation alternate week + No polymer	2.3	4885	575	46	23	65	4.42
LSD (5% level)	0.3	726	125	7	4	10	

Table 11 : Soil properties after harvesting of groundnut crop under polymer (Bhagiratha) and irrigation treatments during *rabi* season in HRF

Soil parameters	After harvesting groundnut					LSD (5% level)
	T1	T2	T3	T4	T5	
Organic carbon (%)	0.51	0.48	0.53	0.50	0.49	NS
Available N (kg/ha)	159.9	172.5	197.6	235.2	172.5	32.2
Available P (kg/ha)	22.81	22.94	20.45	31.97	22.44	5.6
Exchangeable K (kg/ha)	168.4	173.2	181.2	210.2	186.2	35.8

Table 12 : Yield, LAI (Leaf area Index at 71 Days after transplanting), water productivity and nutrient uptake for tomato under polymer (Bhagiratha) and irrigation treatments during *rabi* season in HRF

Treatment	LAI	Dry biomass yield	Fruit Yield	Total N Uptake	Total P Uptake	Total K Uptake	Water productivity
				Kg/ha			kg fruit ha/mm
T1, Irrigation every week + polymer @ 100 kg/ha	4.2	9875	65063	119.0	85.5	126.0	209.9
T2, Irrigation alternate week + polymer @ 100 kg/ha	2.8	4464	31777	55.7	40.4	58.5	198.6
T3, Irrigation every 3rd week + polymer @ 100 kg/ha	2.1	3509	27875	46.1	33.9	47.8	278.8
T4, No irrigation + polymer @ 100 kg/ha	1.7	1625	13645	21.9	16.2	22.6	
T5 Irrigation alternate week + No polymer	2.7	3964	25954	47.6	34.2	50.5	162.2
LSD (5% level)	0.3	1210	2551	10.2	6.5	12.0	

irrigation water, the amount of rainfall received during crop growth was 57.9 mm. Water productivity was computed using groundnut pod yield data and total amount of water applied during crop growth period. Application of polymers at 100 kg/ha with alternate week irrigation recorded the highest water productivity of 4.78 kg/ha/mm and saved 130 ha-mm irrigation water during groundnut crop growth.

Results pertaining to soil properties studied after the harvest of rabi groundnut indicated (Table 11) that there was no significant difference between initial soil organic C, available P and exchangeable K levels and the levels recorded after the harvest of crop, except in case of available N. Available N content in soil was comparatively higher after harvesting of groundnut than at initial stage, may be because of biological N fixation by crops.

Rabi tomato fruit yield was as high as 65.06 t/ha in T1 treatment where polymer was applied @ 100 kg/ha along with irrigation in every week (Table 12). Every week irrigation with polymer treatment plots could effectively maintain soil moisture near field capacity in entire crop growth period which produced the tomato yield more than 3 times the *kharif* yield; however, the yield was reduced to 50% in T2, when irrigation frequency was reduced to every alternate week.

There was no significant difference in yield between treatment T3 (with polymers @ 100kg/ha and every 3rd week irrigation) and T5 (without polymers and irrigation at alternate week). The results indicated that at least one irrigation in every three weeks can be postponed by applying polymers as T3 and T5 recorded similar yield level. Even treatment T4 having 100 kg/ha polymers without any irrigation gave a yield of 13.64 t/ha. During the crop growth period, a total of 57.9 mm rainfall was received in three rainy days. Light irrigation was applied for initial crop establishment and at the time of fertilizer application in T4 treatment. In case of T1 treatment, total 310 mm (16 numbers of irrigation) in T2 and in T5, total 160 mm (8 numbers of irrigation) and in T3, total 100 mm (5 numbers of irrigation) water was applied as irrigation.

The data on water productivity as computed using fruit yield data and total amount of water applied during crop growth period indicated that application of polymer at 100 kg/ha with every 3rd week of irrigation recorded the highest water productivity of 279 kg/ha/mm and saved 210 ha-mm water for entire crop growth period.

Effect of different treatment combinations on total dry matter production of tomato was essentially similar to that of fruit yield. Super absorbent polymer resulted in improvement in plant growth by increasing water holding capacity in soils (Boatright *et al.*, 1997).

Treatment combinations comprising irrigation levels and polymer application significantly influenced the nutrient (N, P, and K) uptake /removal by tomato. In general, the trend effect of different treatments on nutrient uptake by tomato was similar to that of fruit yield and dry matter production. Shim *et al.* (2008) also observed the increase in N, P, K, Ca and Mg uptake on hydrophilic polymer treated plots as results of better plant growth. There was decrease in nutrient N content in soils during the harvesting stage in T1 treatment (Table 11) which may be because of higher uptake of nutrients by plants, on the other hand soil nutrients were higher in T4 treatment, may be because of less yield and less uptake.

In the laboratory studies, hydrogel polymers retained about 332-465 g water per g and thereby increased the available water of light textured soil. The results of laboratory studies were reflected in the field studies. The stored water in the polymer is released as required by the crop and used to meet the crop water requirement. Effect of water absorbing polymers as soil amendments were also investigated in semiarid region of Mongolia in sandy loam soils and there was 4.2-32.9% increase in tuber yield and increase in tuber size of potato was recorded (Xu *et al.*, 2015). The soil amendments also improved soil water holding capacity, soil cone penetration resistance and soil aggregate size fractions. Narjary *et al.* (2012) also reported that hydrogel is highly suitable for raising agricultural crops particularly vegetables in alluvial and red sandy loam soils as the water availability to plants grown in gel treated soils increased by 1.5-2 times over the water available to plants grown in non-gel –treated soil and increase the irrigation interval, but it was found unsuitable for black soils.

Conclusions

Polymers help in retaining soil moisture by holding water in soil, and most of the water retained is available to plant. During the year 2010, 48 % higher annual rainfall occurred over the normal rainfall and plants hardly suffered any dry spell during *kharif* season. There was no yield benefit for groundnut and pigeonpea crop after application of polymers because of good distribution of rainfall during crop growth period. However, tomato fruit yield was increased under situation where polymer was applied. The agronomic efficiency of polymers application for tomato was 58 kg tomato per kg of polymer application when polymers were applied @50kg/ha. The results for tomato during *rabi* season indicated that at least one irrigation in every three weeks can be postponed by applying polymers. Tomato is indeterminate type crop where flowering occurs in flushes. Polymers may help in retaining soil moisture towards the maturity stage of crop and increased the number of pickings. To get the best results, polymers should be applied at the root zone of crop at 10 cm soil depth through dibbling. Even application in rows was also not much effective.

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